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High Efficiency White Organic Light-Emitting Diodes with Tandem Structure

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1. Introduction

Recently, organic light-emitting diode (OLED) is a promising display technology due to the advantages of self-emission, high brightness, and potentially low cost. Especially, white OLEDs (WOLEDs) have attracted interest of many due to its their applications to full-color displays combined with RGB color filters and illuminant light sources [1]. To achieve both high brightness and efficiency, tandem structure OLEDs consisting of multiple electroluminescent (EL) elements connected in series have been introduced [2-4]. The luminance efficiency scales almost linearly with the number of EL units in the tandem devices. However, few reports discuss the performance and stability of the tandem WOLEDs. In the present work, we propose a high efficiency WOLED with tandem structure by using a charge generation layer (CGL) of Li-doped Alq_3 [5] and MoO*x*-doped 2-TNATA [6] as an effective interconnecting layer to connect the individual EL unit for realizing high performance tandem WOLEDs.

2. Experimental Methods

Figure 1 shows the structure of two devices that were fabricated.

Control device: ITO/*p*-HIL(80 nm) / white EL unit/*n*-ETL (5 nm)/Al (200 nm).

Tandem device: ITO/*p*-HIL(80 nm)/ white EL unit/*n*-ETL (5 nm)/*p*-HIL(80 nm)/ white EL unit/*n*-ETL (5 nm)/Al (200 nm).

Two single white EL units with the same structure of NPB : 3% Rubrene / Anthracene : 3% Perylene are connected by the proposed CGL of 50 wt % Li-doped Alq_3 (*n*-ETL) and 10 wt % MoO*x*-doped 2-TNATA (*p*-HIL).

Both devices were grown on glass substrate precoated with a 260 nm thick layer of ITO having a sheet resistance of 7 ohm/square. The ITO surface was treated by UV-ozone before it was loaded into an evaporator. All organic layers were sequentially deposited onto the substrate at room temperature by thermal evaporation from resistively heated tantalum boats at the rate of ~0.1-0.2 nm/s and a base pressure of under 10^{-5} Pa. The voltage-current density-luminance (V-J-L) characteristics and EL spectra were simultaneously with a programable Keithley 2400 power source and a Photoresearch PR650 spectrometer. All of the measurements were made in the air at room temperature.

3. Result and Discussion

The inset of Fig. 2 shows transmittance of Li-doped Alq_3 (5 nm)/MoO*x*-doped 2-TNATA (80 nm) bilayer thin film. This interconnecting layer is transparent in the blue-red range of 400 to 800 nm, which is essential to achieve an efficient tandem WOLED for solid-state lighting applications. Figure 2 plots the current density-voltage characteristics of the control and tandem devices. It can be seen that at any current density the driving voltage of the tandem device is about twice that of the control device. However, the CIE coordinates of white emission in tandem device slightly change from (0.311, 0.396) to (0.284, 0.369) with the driving voltage increases from 8 to 16V.

As shown in Fig. 3, at a current of 20 mA/cm^2, luminous efficiency of the control device is 7.71 cd/A, while that of the tandem device remarkably increases to 18.81 cd/A. Similarly, the luminances of the control and tandem devices are 1520 and 3800 cd/m^2, respectively. These values clearly demonstrated that the enhancement of EL efficiency is attributed to the effectiveness of the conductive *p-n* junction in electrically connecting two EL units.

Figure 4 plots the dependence of power efficiency and external quantum efficiency versus current density of the control and tandem devices. The power efficiency of the control and tandem devices reaches 4.32 and 5.48 lm/W at 20 mA/cm^2, respectively. And as a result, the tandem device achieved an external quantum efficiency of 6.5%, which is about two times greater than that of the control device.

Figure 5 shows the normalized EL intensity versus the viewing angle characteristics of the control and tandem devices. It is observed that both devices are approximately the same characteristics of EL intensity. This suggests that the tandem device shows weak micro-cavity effect due to the high transmittance (low reflectively) of the CGL as shown in the inset of Fig.1. The inset of Fig. 5 shows normalized EL spectra of the control and tandem devices at 20 mA/cm^2. It is clearly seen that the EL spectrum of the tandem device changed very slightly with respect to the control device. However, there is weak peak at 505 nm in tandem device, which can be attributed to the optical effect stemming from the different optical paths of the emitted light [7].

4. Conclusions

In summary, we demonstrated high efficiency WOLED with tandem structure by using Li-doped Alq_3/MoO*x*-doped 2-TNATA as an interconnecting layer. The tandem device exhibited luminance of 3800 cd/m^2, a luminous efficiency of 18.81 cd/A, a power efficiency of 5.48 lm/W, and external quantum efficiency of 6.5% at 20 mA/cm^2. The enhanced EL efficiency is attributed to Li-doped Alq_3/MoO*x*-doped 2-TNATA formation of an intrinsic *p-n* junction, which fulfills the prerequisite as a connecting unit and lead to dramatic performance improvement in the tandem WOLED. It was found experimentally that the EL intensity versus the viewing angle characteristics of the tandem device is approximately the same as control device.

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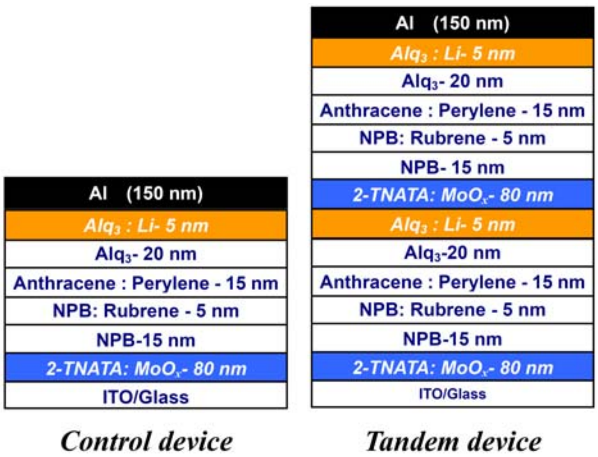

Fig. 1. Schematic diagram of the control and tandem WOLEDs.

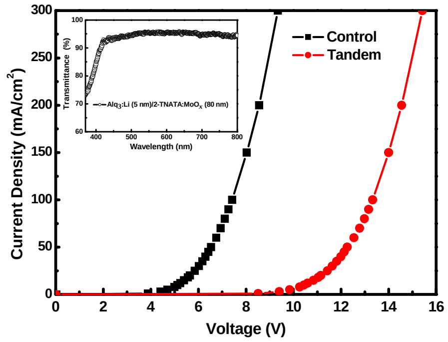

Fig. 2. Current density-voltage characteristics of the control and tandem WOLEDs. Inset : transmittance spectrum of Li-doped Alq_3 (5 nm)/MoO_x-doped 2-TNATA (80 nm) thin film.

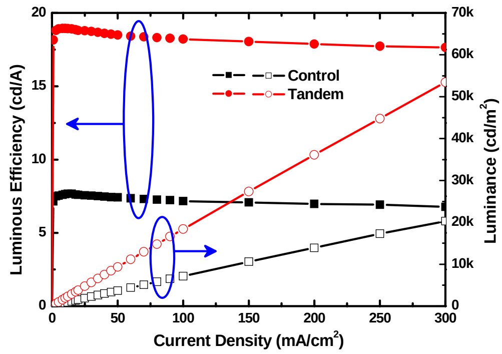

Fig. 3. Luminous efficiency-durrent density-luminance characteristics of the control and tandem WOLEDs.

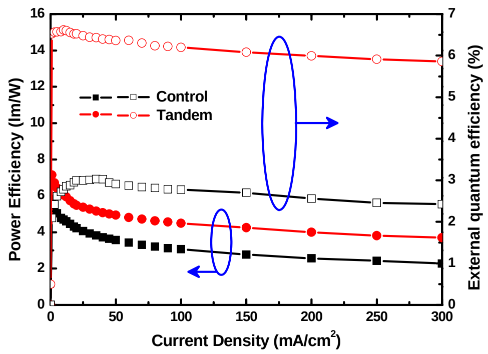

Fig. 4. Power efficiency-durrent density-exernal quantum efficiency of characteristics of the control and tandem WOLEDs.

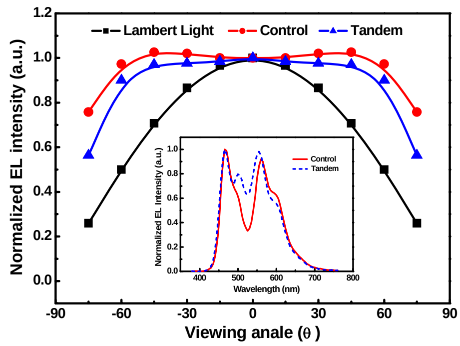

Fig. 5. Normalized EL intensity-viewing angle characteristics of the control and tandem WOLEDs. Inset : EL spectra of the control and tandem WOLEDs.